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Studies on Normal Incidence Backscattering in Nodule Areas Using the Multibeam-Hydrosweep System

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Abstract

The acoustic response from areas of varying nodule abundance and number densities in the Central Indian Ocean has been studied by using the echo peak amplitudes of the normal incidence beam in the Multibeam Hydrosweep system. It is observed that in areas of higher nodule abundance, the acoustic response is more deterministic. The coefficient of variation of the echopeak amplitude is observed to be the highest for areas with medium nodule abundance and number densities.

Introduction

Manganese nodule deposits have been the focus of attention of the international oceanographic community in the past few decades due to its increasing economic importance (Mero, 1965) [1]. Manganese nodule deposits cover millions of square kilometres of the ocean floor. Exploration methods for determining the nodule coverage include combinations of spot sampling and deeptow photographic surveys (Speiss et al., 1973, Weydert, 1985) [2,3]. Both these techniques, however are extremely slow and expensive involving considerable amount of ship time. In contrast, the sounding system can provide faster methods for determining nodule coverage.

The multibeam system serves as an effective tool for mapping the seabed due to its multinarrow beams and wide coverage. Further, it can also be used for bottom characterization using the backscattering applications. In this study, we have used the normal incidence beam of the Hydrosweep system to determine the backscattered signal strength and correlate it with the varying nodule coverage parameters. We have collected the echo signal from seven areas of different known nodule distributions (A-G). Two non-nodule areas (H and I) have been selected for a comparative study. Table I shows the locations of the different study areas and the nodule parameters of the nodule coverage in those areas.

Magnuson (1983) [4] and others (Smith, 1981, Brekhovskikh et al., 1985) [5,6] had shown that the synthesized sound signal response of the nodule deposit is equivalent to the plane wave response off a flat bottom. A study has been performed based on the reflective behaviour to estimate quantitatively the signal response for varying nodule parameters. A comparison of the mean echo peak amplitudes with the theoretically computed values shows that the reflective model has limitations for medium nodule coverage (Gorskaya et al., 1990) [7]. This has been further supported by computing the coefficient of variation of the backscattered peak amplitude from the nodule areas based upon statistical methods enumerated by deMoustier (1985) [8] and Gorskaya et al. (1990).

Nodule Abundance

The nodule abundance in the areas A-F has been shown in Table I. It is observed that areas A-E have a nodule coverage that varies between medium and high, while areas F and G have a low nodule coverage. In areas H and I, nodule existence has not been reported. The nodule sampling was performed using Free Fall Grabs (FFGs) in the survey area. Nodule abundance (kg/m^2) was computed as a ratio of the total weight of nodules retreived in the grab to the area of the grab (≈ 0.13 m^2). The number density was determined by taking an average of the total number of nodules recovered by the grab. The root mean square (rms) radius of the nodules was determined to perform size analysis of the nodules.

ECHO PEAK SIGNALS, LOCATIONS, AVERAGE DEPTH, THEORETICALLY COMPUTED SCATTERED AMPLITUDE AND NODULE DESCREPTIONS OF THE NODULE AREAS.

1. Area	A	B	C	D	E	F	G	H*	I*
2. Locations	14° 13S 74°34E	14°08S 74°45E	13°15S 74°55E	13°58S 74°59E	12°30S 75°56E	11°08S 75°11E	10°05S 75°09E	06°01S 78°55E	01°43S 76°06E
3. Peak Signal (in A/D numbers)									
a. Mean	34.39	35.55	72.52	63.91	27.32	22.54	27.11	139.5	149.0
b. Standard deviation	32.41	30.38	48.86	49.60	18.19	12.14	14.90	51.41	39.28
c. Median	23.67	26.33	57.67	45.50	22.67	21.0	24.33	150.8	152.8
4. No. of samples (peak)	157	361	331	355	409	333	263	188	199
5. Operational depth (average in m.)	5078	5140	5210	5169.3	5220	5185	5220	5163	4781
6. Theoretically computed relative scattered amplitude (dB)	-3.54	-1.94	0.0	-2.66	-6.16	-15.8	-14.48	-	-
7. Nodule details									
a. Number density	230.76	238.46	319	187.17	135.9	43.57	41.0	-	-
b. Abundance (kg/m)	6.15	7.27	17.69	9.0	4.94	2.16	2.06	-	-
c. Average radius (cm)	1.27	1.60	1.53	1.44	1.65	1.70	1.85	-	-
d. Category	medium	medium	high	high	medium	low	low		

* Non nodule area

TABLE I

Multibeam System (Hydrosweep)

An extensive report on the Multibeam system - Hydrosweep installed on ORV Sagarkanya is available in the document prepared by Gutberlet and Schenke (1989) [9]. The Hydrosweep operates at 15.5 KHz. We collected the normal incidence backscattered signal using an additional terminal (WY-85) attached to the bottom echo module. The bottom echo module performs the depth determination. In the Hydrosweep system, the received 72 channels are preamplified, attenuation corrected and consequently 59 beams are formed at the output of the beamforming network. The peak of each beam is available in digital (A/D) units.

Reflectivity Studies on the Normal Incidence Echo

Magnusson (1983) had formulated the individual nodule scattering response to obtain equivalent reflectivity from nodule deposits. We have analyzed the acoustic response variation to different nodule number densities and abundance on the seafloor. The acoustic response is given by

$$|P_{scatt}| = \frac{\Pi \, \zeta_n R_\theta}{k\,a} \left\{ \frac{1}{(1 + j\,\beta/kr)} \right\} \frac{P}{2r} \qquad \text{...... (1)}$$

where 'P' is the transmitted power and is assumed as unity. 'r' is the depth, 'ς_n' is the number density and 'a' is the mean radius of nodules in a given location and 'k' is the operating wavenumber. The values of 'ς_n' and 'a' are determined from the nodule deposits collected by the grab sampler and is displayed in Table I for different areas. Stationary phase integration has been performed on equation (40) of Magnusson (1983) to obtain equation (1). The centre beamwidth parameter of Hydrosweep, 'β' is given as

$$\beta = 4 \ln 2 / (\theta_{1/2})^{1/2} \qquad \text{...... (1.a)}$$

where $\theta_{1/2}$ is the half power beamwidth (2.3°).

R_θ is the scattering amplitude for a single nodule of elastic sphere and is defined as

$$R_\theta = 2\,|f|\,/\,a \qquad \text{...... (1.b)}$$

where $|f|$ is the modulus of the scattering function for elastic sphere having $ka \ll 1$

$$|f| = a(ka)^2 \left\{ \frac{E - [1/(1-1.33\,H^3)] + \mathrm{Cos}\,\theta}{3E} \times \frac{G-1}{2G+1} \right\} \qquad \text{...... (1.c)}$$

'E' in equation (1.c) is expressed as

$$E = \frac{G.\,C_1}{C_0} \qquad \text{...... (1.d)}$$

where C_1 is the longitudinal sound velocity in a nodule and C_0 is the sound velocity in the surrounding medium. C_1 is 2123 m/sec. (Mukhopadhyay and Ramana, 1990) [10] for nodules in the siliceous clay region in the Indian Ocean. The nodules lie in a thin peneliquid layer, often described as the Acoustically Transparent Layer (ATL) (Mukhopadhyay and Nagendernath, 1988).[11] Therefore C_0 is considered as 1500 m/sec.

'G' is expressed as a ratio

$$G = \varsigma_1 / \varsigma_0 \qquad \text{...... (1.e)}$$

ς_1 is the average density of nodules (1.98 gm/cc) and ς_0 is the density of the surrounding medium (ATL; 1.0 gm/cc).

H is expressed as the following ratio

$$H = C_T / C_1 \qquad \text{...... (1.f)}$$

C_T is the transverse sound velocity in nodules and is reported to be 1083 m/sec for the Indian Ocean nodules collected from siliceous sediment zone..

The signal strength for different nodule areas (A-G) are obtained from equation (1) and they are then normalized with the signal strength calculated for area C (highest abundance and number density). These results are displayed in Table I. Table I also shows the mean, median and standard deviation of the experimentally acquired peak signal. It is found that the theoretically computed acoustic response and experimentally obtained peak signal in area D do not agree closely with each other. Area D returns a higher signal strength for the nodule abundance and number density reported in that area. This observation is made by comparing the signal strength returned from area D with the signal strength received from area C. We find that though the signal strengths from area C and area D do not have a large difference, the nodule abundance and the number densities in the two areas vary widely. This is explained by the presence of large ferromanganese encrustations which occur largely as large slabs and big chunks. Such ferromanganese encrustations were recovered during various dredging operations in region D, which often resulted in only a partial recovery of nodules in the free fall grabs (Sudhakar and Sharma, 1985) [12]. In areas other than D, the theoretically computed acoustic response is in accordance with experimental peak values as seen in Table I.

Echo peak Variation

The variation of the acoustic signal response with nodule coverage is evident from the theoretical study and experimentally obtained peak values. However, the variations are not uniform for environments with different nodule parameters. In this regard, we initiated a study to determine the peak amplitude variations for areas with varying nodule coverage. The peak amplitude has been averaged for every 3 transmissions. The peak amplitude is expressed with respect to the mean amplitude of the given area in dB and is shown in figure 1. The centrebeam depth profile for different areas are also included in figure 1. In areas of low nodule abundance(F and G), the peak amplitude varies around 13 dB, whereas in non-nodule areas, the total variation is around 6 dB. Hence, we observe that the peak amplitude response distinguishes between nodule and non-nodule areas. In areas A, B and E, where the nodule abundance is of medium nature, the peak signal variation is around 15 dB, while in the high nodule abundance area (C and D), it is 13 dB. This indicates that the peak signal variation is more in areas with medium nodule abundance. Gorskaya et al. (1990) have showed that the variation of signal response is higher for medium nodule coverage. Our study agrees with this observation. However, we have extended our study by determining the coefficient of variation of the echo peak amplitude.

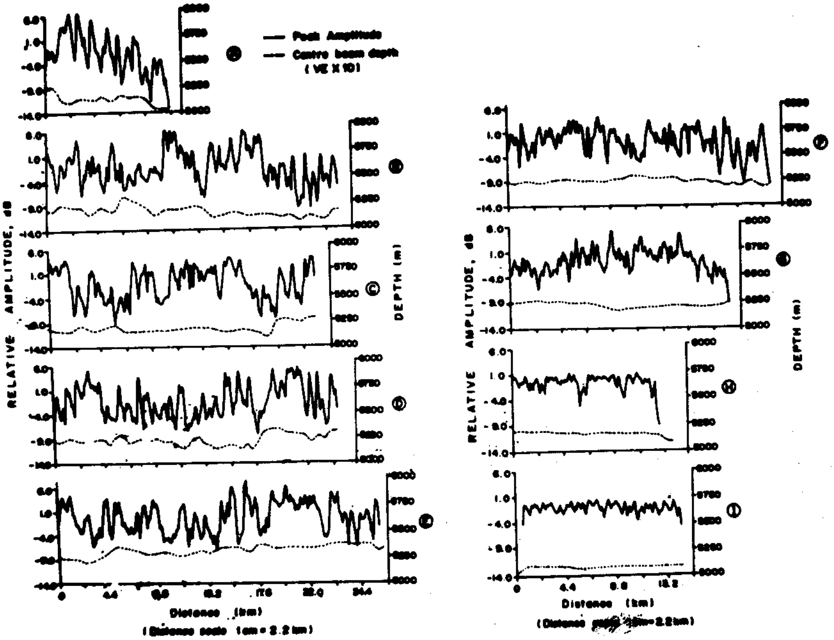

Figure 1. Echo peak amplitude (dB) and centre beam depth profile (vertical exaggeration of 10) versus distance travelled.

The coefficient of variation of the echo peak amplitude is given by

$$\eta = \sqrt{\langle A\rangle^2 - \langle A^2\rangle} / \langle A\rangle \qquad \text{.........(2)}$$

where A is the peak amplitude of the echo from the seabottom. The coefficient of variation computed from equation 2 is found to be higher for medium nodule coverage areas such as A, B and E (0.94, 0.86 and 0.66 respectively), than in areas C and D of higher nodule abundance (0.67 and 0.77 respectively). The coefficient of variation for low nodule abundance areas, F and G are 0.56 and 0.55 respectively.

Conclusion

The theoretically computed acoustic response and the experimentally acquired echo peak amplitudes from areas of known nodule abundance in the Central Indian Ocean points to the fact that there is an increase in acoustic response with increasing nodule abundance and number density. Statistical studies on experimentally collected peak amplitudes show that the coefficient of variation of the acoustic response is higher for medium nodule abundance than for the high and low nodule abundance. Further studies are being performed on topographic variations and sediment nature to explain this anomaly.

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